the capacitor. The unit of capacitance is coulombs per volt, and this unit is called a **farad** (F). Common capacitors have capacitance in the range of 1 pF (picofarad = 10^{-12} F) to $10^3\,\mu$F (microfarad = 10^{-6} F). The relation, Eq. 17–7, was first suggested by Volta in the late eighteenth century.

Unit of capacitance: the farad (1 F = 1 C/V)

From here on, we will use simply V (in italics) to represent a potential difference, such as that produced by a battery, rather than V_{ba} or $V_b - V_a$ as previously. (Be sure not to confuse italic V and C which stand for voltage and capacitance, with non-italic V and C which stand for the units volts and coulombs.)

CAUTION

V = potential difference from here on

The capacitance C does not in general depend on Q or V. Its value depends only on the size, shape, and relative position of the two conductors, and also on the material that separates them. For a parallel-plate capacitor whose plates have area A and are separated by a distance d of air (Fig. 17–13a), the capacitance is given by

Capacitance depends only on physical characteristics of the capacitor, not *on Q or V*

$$C = \epsilon_0 \frac{A}{d}. \qquad \text{[parallel-plate capacitor]} \quad \textbf{(17–8)}$$

We see that C depends only on geometric factors, A and d, and not on Q or V. We derive this useful relation in the optional subsection on the next page. The constant ϵ_0 is the *permittivity of free space*, which, as we saw in Chapter 16, has the value $8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2}$.

EXAMPLE 17–8 **Capacitor calculations.** (*a*) Calculate the capacitance of a parallel-plate capacitor whose plates are 20 cm × 3.0 cm and are separated by a 1.0-mm air gap. (*b*) What is the charge on each plate if a 12-V battery is connected across the two plates? (*c*) What is the electric field between the plates? (*d*) Estimate the area of the plates needed to achieve a capacitance of 1 F, given the same air gap d.

APPROACH The capacitance is found by using Eq. 17–8, $C = \epsilon_0 A/d$. The charge on each plate is obtained from the definition of capacitance, Eq. 17–7, $Q = CV$. The electric field is uniform, so we can use Eq. 17–4b for the magnitude $E = V/d$. In (*d*) we use Eq. 17–8 again.

SOLUTION (*a*) The area $A = (20 \times 10^{-2}\,\mathrm{m})(3.0 \times 10^{-2}\,\mathrm{m}) = 6.0 \times 10^{-3}\,\mathrm{m^2}$ The capacitance C is then

$$C = \epsilon_0 \frac{A}{d} = (8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2}) \frac{6.0 \times 10^{-3}\,\mathrm{m^2}}{1.0 \times 10^{-3}\,\mathrm{m}} = 53\,\mathrm{pF}.$$

(*b*) The charge on each plate is

$$Q = CV = (53 \times 10^{-12}\,\mathrm{F})(12\,\mathrm{V}) = 6.4 \times 10^{-10}\,\mathrm{C}.$$

(*c*) From Eq. 17–4b for a uniform electric field, the magnitude of E is

$$E = \frac{V}{d} = \frac{12\,\mathrm{V}}{1.0 \times 10^{-3}\,\mathrm{m}} = 1.2 \times 10^4\,\mathrm{V/m}.$$

(*d*) We solve for A in Eq. 17–8 and substitute $C = 1.0\,\mathrm{F}$ and $d = 1.0\,\mathrm{mm}$ to find that we need plates with an area

$$A = \frac{Cd}{\epsilon_0} \approx \frac{(1\,\mathrm{F})(1.0 \times 10^{-3}\,\mathrm{m})}{(9 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2})} \approx 10^8\,\mathrm{m^2}.$$

NOTE This is the area of a square 10^4 m or 10 km on a side. That is the size of a city like San Francisco or Boston! Large capacitance capacitors will not be simple parallel plates.

Not long ago, a capacitance greater than 1 μF was unusual. Today capacitors are available that are 1 or 2 F, yet they are just a few cm on a side. Such capacitors are used as power backups, for example, in computer memory and electronics where the time and date can be maintained through tiny charge flow.

PHYSICS APPLIED

Capacitor as power backup